SPRING-DASHPOT VIBRATION ISOLATORS AGAINST EARTHQUAKES

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SUMMARY

By making use of analytical procedures the advantages of the spring-dashpot vibration isolation system over neoprene pads are explained. Neoprene pads are found to be inadequate to provide vibration isolation for vertical and rocking motions. The spring-dashpot vibration isolation system however is determined to be very efficient in all horizontal, vertical and rocking motions.

INTRODUCTION

The cost of achieving earthquake resistant design by means of conventional methods for important structures like industrial buildings and nuclear power plants is not only excessively high but also the degree of built-in safety is not reliable. Because, the structure is permitted to experience large amounts of plastic deformations which may cause complete damage of the secondary elements like partition walls, installations, etc.

Contrary to contemporary earthquake resistant design procedure, vibration isolators enable the structure to behave like a rigid body and all deformations and stresses are restricted to remain within the elastic range thus preventing the possibility of damages to any structural or nonstructural elements.

In earlier applications, neoprene pads and some mechanical devices are used for vibration isolation and energy absorption purposes (Ref. 1 to 3). Later, the feasibility of the use of elastic springs and visco-dampers as vibration isolators of structures have been also investigated (Ref.4 and 5). The basic idea behind the vibration isolation is to arrange such a physical system at the base that the natural period of vibration of the structure is pushed quite far away from the predominant period of the disturbing ground motion. In this way, the structure will not be subject to undesirably magnified accelerations. The neoprene pads are equivalent to elastic springs only in the horizontal direction. Their capacity of providing flexibility in the vertical direction is very small. Therefore, the natural periods of vibration of the structure in the vertical and rocking motions will remain almost unchanged when neoprene pads are used. Consequently, the structure and its components will not be safeguarded against vertical and rocking earthquake motions. Spring-dashpot system however, can provide any desirable degree of flexibility in three dimensions. Therefore, complete vibration isolation may be achieved for all types of motions including the vertical and rocking motions, thus resulting in safer and more reliable design against earthquakes.

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ANALYTICAL MODEL AND INPUT MOTIONS

For the purpose of comparing the behaviour of the spring-dashpot isolators with that of the neoprene pads, especially in the vertical and rocking motions, a simple two-storey test frame is selected as shown in Figs. 1 and 2. In order to arrive at the best possible vibration isolation and to discover the relative efficiency of the locations of dashpots, the model was considered to be supported in various ways as shown in Fig. 3. The basic parameters of the analyses are given in Tables 1 and 2.

The test frame is subjected to the N-S and vertical components of the 1940 El Centro earthquake which have been applied first separately and then simultaneously.

The peak ground acceleration is 0.35g ($3.45 m/sec^2$) in the horizontal and 0.21g ($2.06 m/sec^2$) in the vertical directions. The reason for this earthquake to be selected as the input ground motion is that it causes a significant disturbance on structures like the two-storey test frame.

ENERGY ABSORBTION BY VISCODAMPERS

The major handicap in vibration isolation is that the rigid body displacements of the structure may be excessively large. The use of viscodampers however, is an indispensible tool in eliminating these large displacements. The viscodampers[1] provide sufficient amount of damping, up to 20% to 30% of critical damping, in all three directions.

Based on the experimental evidence, the upper limit of the damping supplied by the viscodampers in the vertical direction is taken in this paper, as 20% of the critical value. Once the critical damping ratio β is known, the coefficient of viscosity c is determined, for the first mode of vibration, from

$$c = \frac{4\pi W}{gT} \beta$$

in which, W = total weight of the structure, and T = natural period of vibration of the structure. The coefficient of viscosity in the horizontal direction is assumed to be 60% that of vertical direction.

In the case of neoprene pads, the critical damping ratio in the horizontal direction is assumed as $\beta_h = 0.07$, which corresponds, for the natural period of $T = 1.17$ seconds in the rocking motion, to the coefficient of viscosity of $c = 15.3$ ton-sec/m. No viscous damping is assumed to be present in the vertical direction when neoprene pads are used.

COMPARISON OF THE RESULTS OF ANALYSES

Using a step-by-step direct integration technique, the time history of displacements, velocities and accelerations at each node has been calculated. The main emphasis in the calculations has been to demonstrate the significance of the vertical and rocking motions. It has been shown that in the case of neoprene pads, the vertical accelerations in the structure are

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[1] A specialized manufacturer since 1907 is *GERB, Gesellschaft für Isolierung mbh and Co. Kommanditgesellschaft, Roedernallee 174, 1000 Berlin 51, Germany*

prohibitively large, since these pads are unable to provide vibration isolation in the vertical direction. Although the complete time history response of all the nodes of the two-storey test frame has been obtained, only the summary of the results are given in Figs. 4 and 5. The optimum values of spring coefficients are those corresponding to the natural periods of $T_r = 1.42$ sec in the rocking and $T_v = 0.50$ sec in the vertical motion.

The time history variations of the acceleration and displacement responses of Node 1, due to the combined action of both the horizontal and vertical earthquake input, are illustrated in Figs. 6, 7 and 8. The efficiency of the spring-dashpot system over the neoprene pads is clearly observed in these figures. In order to determine the relative efficiency of the locations of the viscodampers, identical analyses have been performed once placing the viscodampers at the center, then placing them at the extreme edges of the foundation. Response is significantly more reduced in the case when the dampers are located at the edges.

Influence on Axial Forces of Columns

In ordinary structures, the vertical members at opposite sides of the structure, elongate and shorten alternatively, causing the rocking of the system. The step-by-step direct integration displayed that in the spring isolated cases although horizontal displacements being larger than the system with no isolation, the structure sways as a rigid body at any instant of time during the earthquake. Hence, the relative storey displacements are almost nil permitting no stresses and strains to be built up in the structural members. It is computed that the axial forces produced in the lower storey columns 7 and 9 of the model studied are 62.4 tons and 12 tons in the neoprene and spring isolated cases, respectively.

APPLICATION TO NUCLEAR POWER PLANTS

The most interesting application of vibration isolation using the spring-dashpot system would be the main reactor building of a nuclear power plant. The schematic model for the vibration isolation of a typical reactor building is shown in Fig. 9. Most of the results of the parametric study of the test frame discussed above will be equally applicable to the isolation of the reactor buildings, except the amount of calculations would require more time.

The use of viscodampers, instead of neoprene pads, will provide the necessary isolation especially in the vertical vibration of the installations, piping system and appendices, which are vitally important for the safety of the nuclear power plant. The spring and viscodamper arrangement appears to be the most efficient scheme in reducing the response of the piping installations to an earthquake, especially in the vertical direction.

In order to prevent the presence of undue vibrations in nuclear power plants, at small wind loads for instance, the flexible starter pins or couplings should be installed at the base as explained in Ref. 4, such that the vibration isolation is triggered only after the ground motion exceeds a certain allowable value. Similarly, to prevent excessive deflections of the spring system, a series of large capacity safety pins should be also installed to discontinue the vibration isolation after the relative base displacements exceed a tolerable maximum.

When conventional earthquake resistant design principles are followed, the additional cost of construction is normally in the order of 5% to 10% of the overall cost. The additional cost however, is significantly less if springs and dashpots are used as vibration isolators. In fact, based on the preliminary cost-benefit analysis performed on a typical reactor building, the total additional cost of the springs, dashpots and the special second layer foundations, etc., is found to be not greater than 1% to 2% of the overall cost of the reactor building.

CONCLUSIONS

1. The overall response of a structure to a given earthquake ground motion is considerably reduced by means of vibration isolation at its base, since the structure behaves mainly as a rigid body. Consequently, the stresses in structural elements remain in the elastic range providing confidence in design, simplicity in detailing, and economy in overall cost.

2. Spring-dashpot arrangement is found to be more suitable than the neoprene pads for the vibration isolation of structures especially against the vertical motions of earthquakes.

3. The use of viscodampers provides significant energy absorption capacity and reduces the response of the structure considerably. The efficiency is further increased if the viscodampers are placed at the exterior ends of the base.

REFERENCES

1. Skinner, R.I., Beck, J.L., and Bycroft, G.N., "A Practical System for Isolating Structures from Earthquake Attack," Earthquake Engineering and Structural Dynamics, Vol. 3, 1975.

2. Jolivet, F., and Richli, M., "A Seismic Foundation System for Nuclear Power Stations," Transaç. 4 SMIRT, North-Holland Publishing Co., Amsterdam, Aug., 1977, pp. K9/2.

3. Kelly, J.M., Eidinger, J.M., and Derham, C.J., "A Practical Soft Storey Earthquake Isolation System," EERC-77/27, USA, Nov., 1977.

4. Tezcan, S.S., and Çivi, A., "Reduction in Earthquake Response of Structures by means of Vibration Isolators," U.S. National Conference on Earthquake Engineering, Stanford University, California, Aug.,1979.

5. Hüffmann, G., "Spring-Damper Systems for the Support of Structures to Prevent Earthquake Damage," Proc., 7 WCEE, Istanbul, Turkey, Sept., 1980.

TABLE 1- PARAMETERS OF VIBRATION ISOLATION OF THE TWO-STOREY FRAME

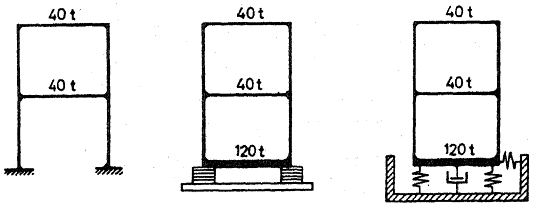
FOUNDATION ISOLATION CASE	SPRINGS (ton/m)		DAMPING (-)		VISCOSITY (t-sec/m)		T = PERIODS (sec)		f = FREQUENCY (Hz)	
	k_v	k_h	β_v	β_h	C_v	$C_h^{(1)}$	Vertical	Rocking	Vertical	Rocking
A. FIXED BASE CASE	∞	∞	0	0	0	0	0.03	0.28	33.33	3.57
B. NEOPRENE PADS	10^5	600	0	7%	0	15.3	0.05	1.17	20.00	0.85
C. SPRING-DASHPOT SYSTEM										
1.Springs only, No dashpots	660	1200	0	0	0	0	0.50	1.42	2.00	0.70
2.Dashpots at the center	330	600	20%	34%(2)	73.2	43.9	0.70	1.99	1.43	0.50
3.Dashpots at the edges (a)	330	600	20%	34%(2)	36.6	43.9	0.70	1.99	1.43	0.50
(b)	660	1200	20%	34%(2)	52.5	63.0	0.50	1.42	2.00	0.70

(1) Viscosity coefficient in the horizontal direction is taken as 60% that of the vertical direction.
(2) Horizontal critical damping ratio is calculated on the basis of the rocking natural period.

TABLE 2- MAXIMUM RESPONSE OF NODE 1 AND 5 OF THE TEST FRAME

INPUT MOTIONS (1940 El Centro Earthquake)	NODE 1				NODE 5			
	FIXED BASE	NEOPRENE PADS	SPRINGS ONLY	SPRINGS AND DASHPOTS	FIXED BASE	NEOPRENE PADS	SPRINGS ONLY	SPRINGS AND DASHPOTS
NATURAL PERIODS (sec)								
Horiz./Rocking	0.28	1.17	1.42	1.42	0.28	1.17	1.42	1.42
Vertical	0.03	0.05	0.50	0.50	0.03	0.05	0.50	0.50
HORIZONTAL EARTHQUAKE($3.45 m/sec^2$)								
Acceleration (m/sec^2) Horiz.	16.90	3.54	4.06	2.18	3.45	3.06	9.46	3.88
Vert.	0.31	0.07	3.65	1.63	0	0.05	3.63	1.63
Displacement (cm) Horiz.	3.14	10.72	12.67	9.88	-	9.93	10.31	3.18
Vert.	0.04	0.04	5.57	2.63	0	0.03	5.55	2.63
VERTICAL EARTHQUAKE($2.06 m/sec^2$)								
Acceleration (m/sec^2) Horiz.	0	0	0	0	0	0	0	0
Vert.	6.57	12.72	2.61	1.21	2.06	7.95	2.59	1.18
Displacement (cm) Horiz.	0	0	0	0	0	0	0	0
Vert.	0.02	0.08	1.61	0.69	-	0.05	1.60	0.68
(HOR+VERT) EARTHQUAKE								
Acceleration (m/sec^2) Horiz.	16.90	3.54	4.06	2.18	3.45	3.06	9.46	3.88
Vert.	6.72	12.73	5.62	1.77	2.06	7.95	5.61	1.73
Displacement (cm) Horiz.	3.13	10.72	12.67	9.88	-	9.93	10.31	3.18
Vert.	0.04	0.10	6.32	2.64	-	0.06	6.30	2.64

Notes: 1. Neoprene pads are assumed to provide 7% critical damping in the horizontal direction.
2. Viscodampers are assumed to provide 20% critical damping in the vertical direction.
3. Viscodampers are placed at the extreme edges of the foundation.



A) Fixed Base B) Neoprene Pads C) Springs_dashpots

FIG. 1- TWO-STOREY TEST FRAME

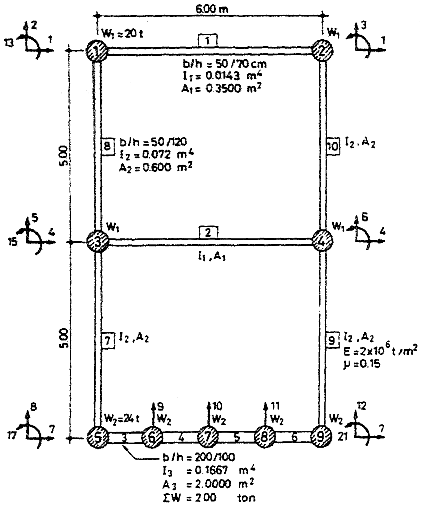
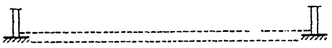
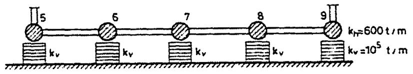


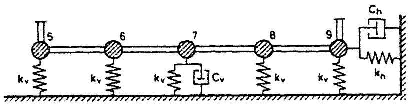
FIG. 2- DATA OF' TEST FRAME



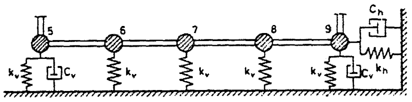
A _Fixed Base Case



B_ Rubber Pads



C _ Dashpots located at the center



D _ Dashpots located at the edges

FIG. 3- VIBRATION ISOLATION CASES

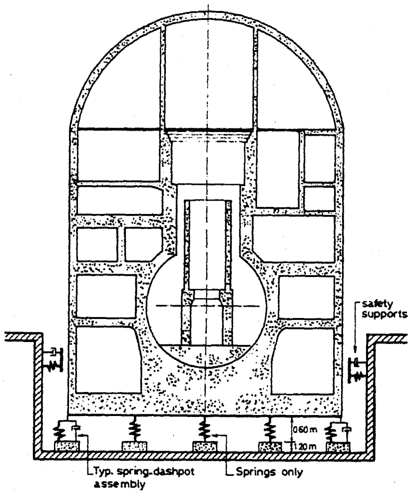


FIG. 9- SPRING ISOLATION FOR A TYPICAL NPP

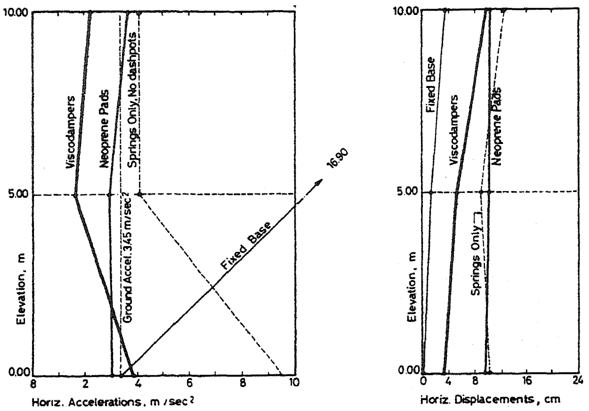


FIG. 4- MAXIMUM HORIZONTAL RESPONSE

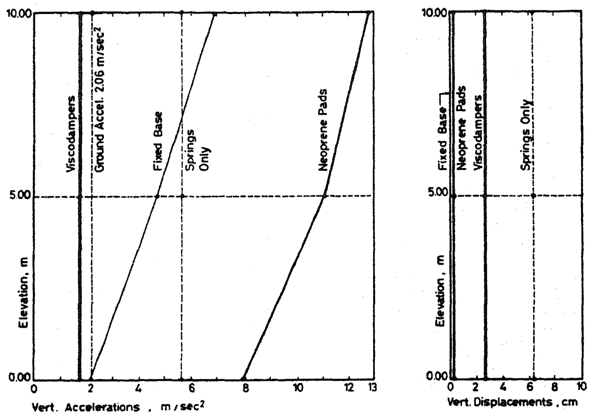


FIG. 5- MAXIMUM VERTICAL RESPONSE

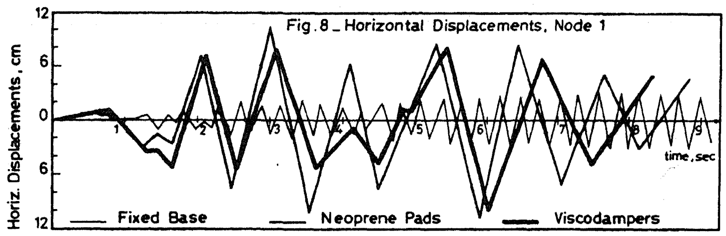


Fig. 8 _ Horizontal Displacements, Node 1

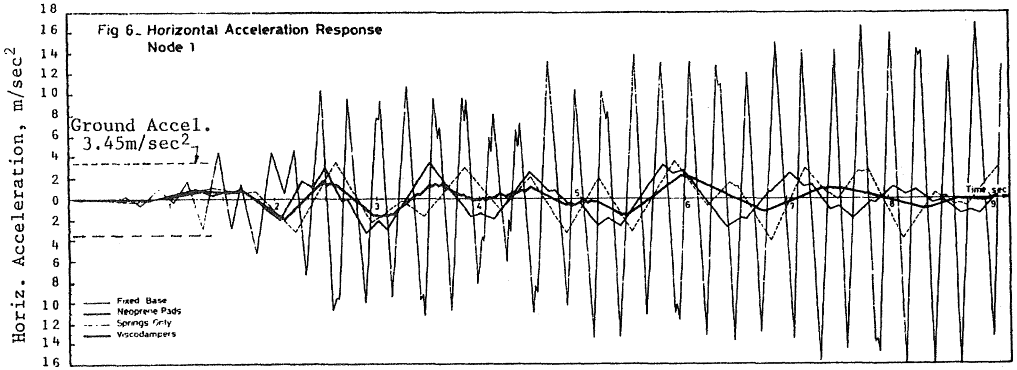


Fig 6_ Horizontal Acceleration Response
Node 1

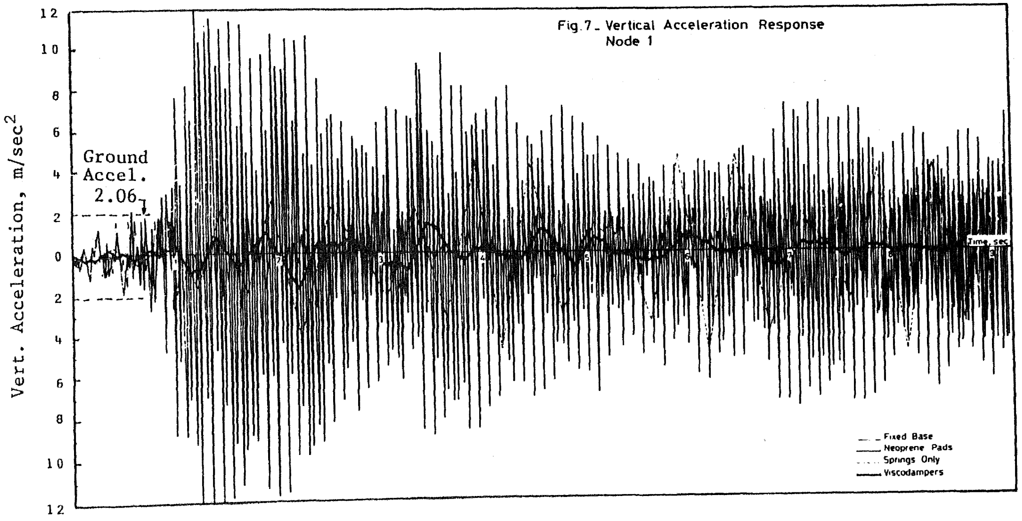


Fig.7_ Vertical Acceleration Response
Node 1